



NRL/MR/7320--12-9448

Generating Delft3D Boundary Conditions Using the Navy Coastal Ocean Model

KACEY EDWARDS

*Ocean Dynamics and Prediction Branch
Oceanography Division*

TIFFANY NGUYEN

DAVID SITTON

*QinetiQ North America
Slidell, Louisiana*

December 20, 2012

Approved for public release; distribution is unlimited.

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY) 20-12-2012		2. REPORT TYPE Memorandum Report		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE Generating Delft3D Boundary Conditions Using the Navy Coastal Ocean Model				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER 0602435N	
6. AUTHOR(S) Kacey Edwards, Tiffany Nguyen, ¹ and David Sitton ¹				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER 73-4546-02-5	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Research Laboratory Oceanography Division Stennis Space Center, MS 39529-5004				8. PERFORMING ORGANIZATION REPORT NUMBER NRL/MR/7320--12-9448	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of Naval Research One Liberty Center 875 North Randolph Street, Suite 1425 Arlington, VA 22203-1995				10. SPONSOR / MONITOR'S ACRONYM(S) ONR	
				11. SPONSOR / MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES ¹ QinetiQ North America, Slidell, LA 70461					
14. ABSTRACT The Delft3D modeling system is often used to provide operational forecasts of littoral hydrodynamics. One method of providing boundary conditions to the system is to extract data from regional model results. Software was developed to extract data from results of the Navy Coastal Ocean Model (NCOM) and to write Delft3D-FLOW boundary conditions. The software was used to generate boundary conditions for a variety of Delft3D-FLOW scenarios, and the generated boundary conditions were compared to the NCOM data. Furthermore, because the Delft3D-FLOW scenarios resolved the environment on the same order of magnitude as the NCOM data, the Delft3D-FLOW results and NCOM results were compared. These tests show that 1) the software accurately extracts data from NCOM results, 2) the software writes the boundary condition files needed for Delft3D-FLOW both 2D and 3D applications, and 3) the Delft3D-FLOW results agree with the NCOM results.					
15. SUBJECT TERMS Delft3D Circulation Nearshore Boundary specification					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (include area code)
Unclassified Unlimited	Unclassified Unlimited	Unclassified Unlimited	Unclassified Unlimited	15	Kacey Edwards 228-688-5077

CONTENTS

I. Introduction.....	1
II. Approach.....	1
A. Initial and Boundary Condition Generation Routines.....	1
B. Test Cases.....	3
1) Maui.....	3
2) Hawaii.....	3
C. Tests.....	3
III. Results.....	3
A. Initial Condition File Generation.....	3
B. Boundary Condition File Generation.....	6
C. Model-Model Comparisons.....	6
1) Maui 3D Case.....	6
2) Hawaii Case.....	9
3) Maui 2D Case.....	11
IV. Conclusions.....	11
V. Acknowledgment	12
VI. References.....	12

I. INTRODUCTION

Delft3D has proven to be a valuable tool in predicting nearshore, high resolution hydrodynamics [a]. The Delft3D-FLOW module solves the Navier-Stokes equations under shallow water, Boussinesq approximations [b,c]. It can be fully coupled with Simulating Waves Nearshore (SWAN), which is the Delft3D-WAVE module [d]. Several types of boundary conditions can be specified for the flow module. Combinations of the boundary condition types can be utilized and are recommended.

While tidal databases can be used to provide boundary conditions to the Delft3D-FLOW module, it is known that these data are often inaccurate in the coastal regions because of low spatial resolution in regions with small water depths. An alternative to using tidal database information to drive Delft3D flow is to utilize boundary conditions from operational regional model output that has global tides included in the solution. For Delft3D circulation computations, the regional model providing boundary conditions is the Navy Coastal Ocean Model (NCOM) [e]. To aid in the automation of Delft3D forecasting, scripting and routines have been developed to generate Delft3D initial and boundary condition files given a Delft3D setup and NCOM output files in netcdf format (nc-files). Using the regional model for boundary conditions has several benefits. First, it may be more resolved in the coastal region than a tidal database, and regional models like NCOM make use of available data to provide the best possible environmental forecast. A drawback is that a Delft3D simulation often has to wait for the regional model to complete before beginning the Delft3D forecast.

This report provides a qualitative look at generated initial and boundary condition files to first ensure that the NCOM data is properly written to the Delft3D files. Secondly, a qualitative comparison between the NCOM data and Delft3D model results is made. The following section briefly describes how the boundary condition generation routines work, the model test cases that are considered and the tests that are performed. The third section reports the results from the tests for each model test case, and conclusions are presented in the final section.

II. APPROACH

A. Initial and Boundary Condition Generation Routines

The boundary condition generation routines use several tools to create Delft3D boundary condition files given regional NCOM model results, and they work in an automated fashion requiring limited interaction from the user beyond calling the routines. Because the process utilizes Matlab, the first step in generating boundary condition files is to subsample the NCOM model results given the Delft3D domain and write the results to files in native Matlab format (mat-files). The user is required to provide only the NCOM nc-file naming convention, the main Delft3D input file (md-file) name, and the directory to which the mat-files will be written. The routines read the Delft3D md-file to determine the area to subsample based on the Delft3D grid file, and mat-files of the needed or desired NCOM data fields are generated.

Once the mat-files are generated, the master routine is executed by the user to generate the needed boundary condition files. Again, the user provides the location of the mat-files created in the preprocessing step, the Delft3D md-file name, and the directory with all the Delft3D input files. The host of routines reads the md-file to determine the Delft3D domain from the grid file and whether it is a 2D or a 3D simulation, the type of boundary conditions used for the forecast, and the boundary points where information is required. With this information, the routines use

interpolation in space (2D and 3D) and time to create Delft3D bct- and bcc-files. A bct-file is generated if water level, velocity, or Riemann boundary conditions are specified for the Delft3D forecast. A bcc-file is generated when temperature and salinity are needed as boundary conditions for 3D forecasts.

In addition to generating boundary condition files, the routines generate initial condition files given the NCOM model results. The same methods of information gathering and interpolation used to generate the boundary condition files are used to generate the initial condition files (ini-files).

Often, regional NCOM models and Delft3D models have very different grid resolutions and probably different bathymetry sources, with NCOM resolution typically much lower than that used for Delft3D. Not having NCOM data where Delft3D needs data is overcome by using a mechanism referred to as internal diffusion. Internal diffusion is a smoothing process that acts to fill in areas void of data without changing the available data and without causing discontinuities in results. In our 3D test cases, it is evident in profile comparisons that the NCOM and Delft3D models have different bathymetries. This is shown in Figure 1. In these situations, internal diffusion is used provide Delft3D the “smoothed” information it needs given the available (low-resolution) NCOM data.

The Delft3D initial and boundary condition generation routines fit into the forecast scripting framework. This allows the boundary condition files to be generated when data from new NCOM forecasts are available. In addition, limited user interaction is required beyond the initial model configuration.

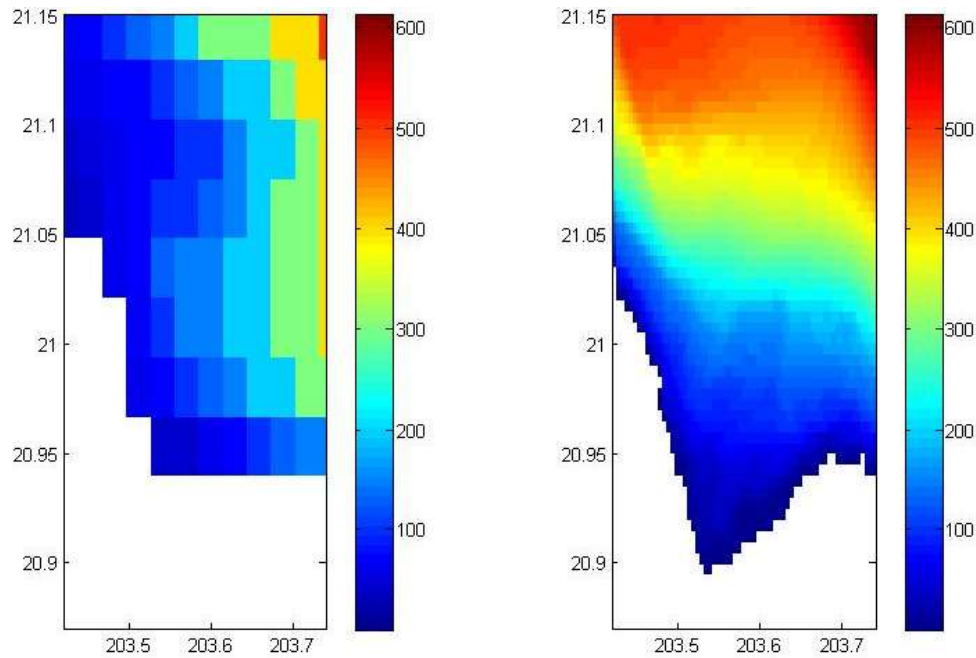


Figure 1. Comparison of NCOM (left) and Delft3D (right) bathymetries for the Maui domain.

B. Test Cases

1) *Maui*

The Maui test case has two components—Delft3D 2D and 3D applications. For both applications the Delft3D domain has a horizontal resolution of approximately 500 meters. The 3D application uses 20 vertical σ -layers distributed so that the surface and bottom of the water column is most resolved. The regional NCOM output providing boundary conditions has a horizontal resolution of three kilometers. The NCOM nc-files provide output at depths of 0, 2.5, 7.5, 12.5, 18, 25, 32.5, 40, 50, 62, 75, 100, 125, 150, 200, 300, ..., 1500, 1750, 2000, ..., 5000 meters. Not all of these depth bins are in the bathymetric range; some are deeper. The 2D Delft3D application requires time series of water levels on the west, north, and east boundaries from the NCOM model; temperature and salinity are ignored. The 3D application requires time series of water level and velocities to compute Riemann boundary conditions and time series of temperature and salinity for the constituent boundary condition. For this test case, both Delft3D applications neglect wind effects, and we will consider the time period of 1-4 September 2008.

2) *Hawaii*

The Hawaii test case is a 3D Delft3D application. The Delft3D horizontal resolution is approximately 200 meters, and it has 20 equally spaced vertical z-levels. A 3-kilometer regional NCOM provides data for the Delft3D boundary conditions, which are Riemann, temperature and salinity on the North, South, and West boundaries. The Delft3D model neglects wind effects.

C. Tests

Qualitative comparisons are used to ensure that the Delft3D and boundary condition generation routines correctly write the Delft3D boundary condition files and to investigate the model results. For comparing a model field (e.g. temperature, velocity, etc.), with respect to the Delft3D domain area, Delft3D data is interpolated to the NCOM grid in horizontal space. For 3D model fields, NCOM data is interpolated to Delft3D vertical levels. With model data on the same horizontal and vertical grids, a difference can be taken. This method is used in the comparison of NCOM data and Delft3D initialization files and the comparison of NCOM data and Delft3D results. For profile and time series comparisons of model fields, three Delft3D grid points are chosen and NCOM results are interpolated to these points. For profile comparisons of temperature and salinity, NCOM is not interpolated with respect to depth. NCOM is interpolated with respect to depth for profile comparisons of velocity error, given as

$$\|D3D - NCOM\| = \sqrt{(u_{D3D} - u_{NCOM})^2 + (v_{D3D} - v_{NCOM})^2}.$$

Two types of comparisons are made. Comparisons between the NCOM data and the generated Delft3D initialization and boundary condition files are referred to as boundary condition comparisons. Comparisons between the NCOM data and Delft3D model results are referred to as model-model comparisons.

III. RESULTS

A. Initial Condition File Generation

Comparisons between data in the NCOM nc-files and the Delft3D initialization files created from the NCOM data indicate that the initialization files are written correctly and contain the proper information provided by NCOM. Figure 2 shows comparisons of water elevation and velocity for the Maui2D test case. For both properties, difference plots over the area covered by

NCOM show minimal differences with values much less than 0.01 meters and meters per second, respectively.

A comparison of water elevation from the NCOM data and the Delft3D initialization file for the Maui 3D case is not shown because it is a duplicate of the top row of Figure 2 showing less than a 0.01 meter difference. Comparisons of temperature and salinity for the Maui 3D case are presented in Figure 3. Differences are shown for the top, middle, and bottom Delft3D layers. These layers correspond to near surface, mid-depth, and near bottom depths, respectively. In addition, profile comparisons for three points in the Delft3D domain are shown in Figure 4. Like surface elevation, the salinity comparisons show little difference (less than 0.01) between the NCOM data and Delft3D's initialization file for the surface and bottom layers and the mid-layer (less than 0.01 and 0.02, respectively). The temperature comparisons are slightly more different. In the top level, temperatures differ by less than 0.04 degrees C. The difference increases but remains less than 0.09 degrees C at mid-depths, and it is less than 0.07 degrees C near the bottom. When the differences are considered relative to the ranges of temperature and salinity over depth, the differences are negligible. The bottom row of Figure 4 shows the velocity error with respect to depth at three observation points labeled A, B, and C (Figure 3) in the Delft3D domain. For all three points, the error is negligible with values much less than 5 cm/s.

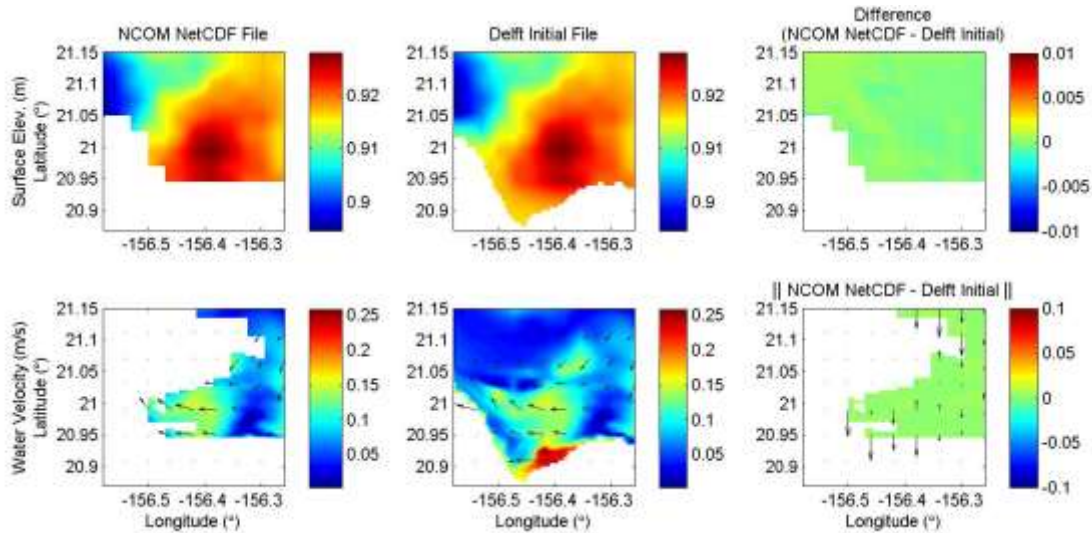


Figure 2. Comparison between the available NCOM data (from the nc-files) and the Delft3D initialization file for the Maui 2D case.

Comparisons between the NCOM data and the Delft3D initialization file show good agreement for the Hawaii test case. In Figure 5, differences in surface elevation are less than 0.01 meters. In addition, Figure 5 shows the effects of internal diffusion. Note that in the middle plot, initial Delft3D surface elevations match the NCOM data and for the Delft3D grid points not covered by the NCOM grid, smoothed parameter values are applied. It is important to see that the values provided by NCOM are unchanged by the internal diffusion.

For the Hawaii case, differences between the NCOM data and Delft3D initialization file are less than 0.01 for the three dimensional properties of temperature, salinity, and velocity, too. Figure 6 shows the comparison for salinity. Note that in creating the initialization file, internal diffusion fills the Delft3D grid at z-levels where no data is expected. The Delft3D areas of

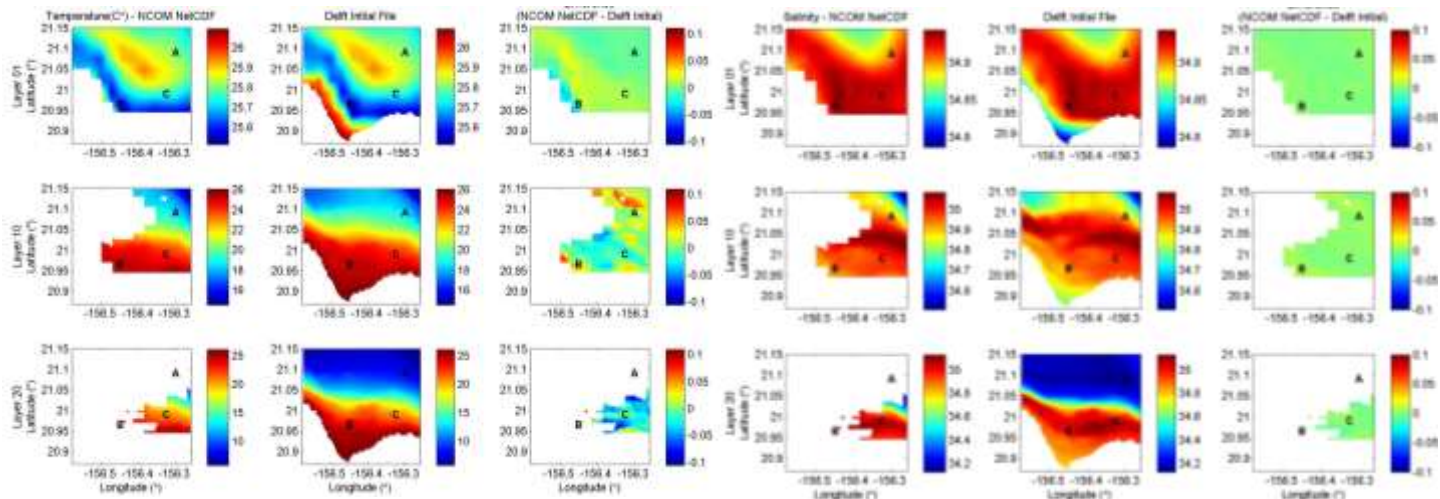


Figure 3. Comparisons between the available NCOM data (from the nc-files) and the Delft3D ini-file for the Maui 3D case for temperature (left) and salinity (right).

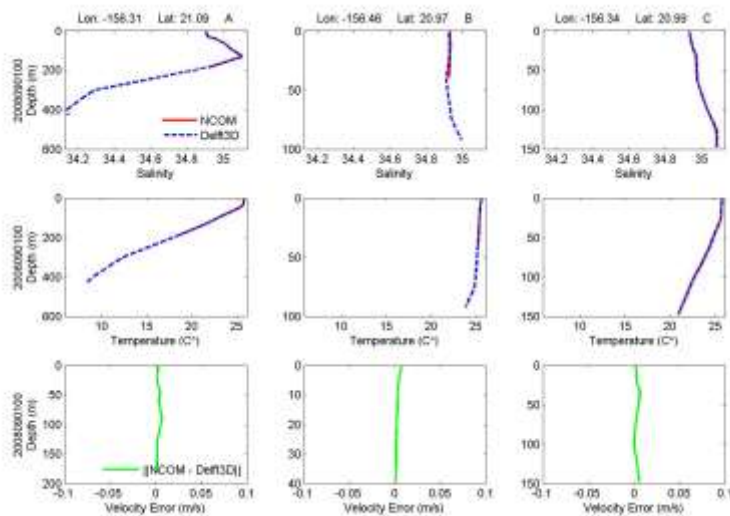


Figure 4. Comparisons between the available NCOM data (from the nc-files) and the Delft3D ini-file for the Maui 3D case for salinity (top), temperature (middle), and velocity (bottom) at three points in the Delft3D domain, Points A (left), B (middle), and C (right).

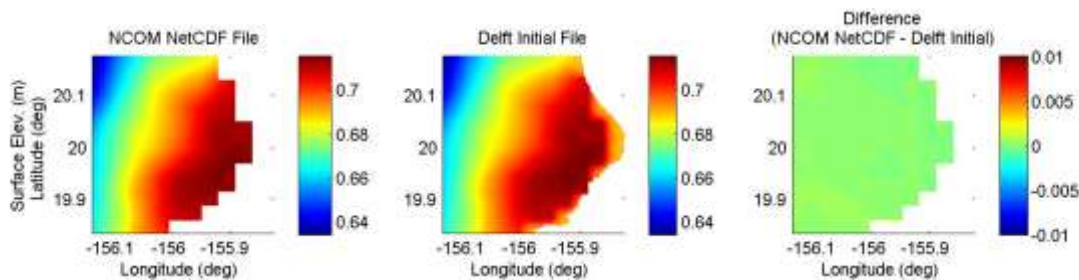


Figure 5. Water level comparisons between the available NCOM data (from the nc-files) and the Delft3D ini-file for the Hawaii case.

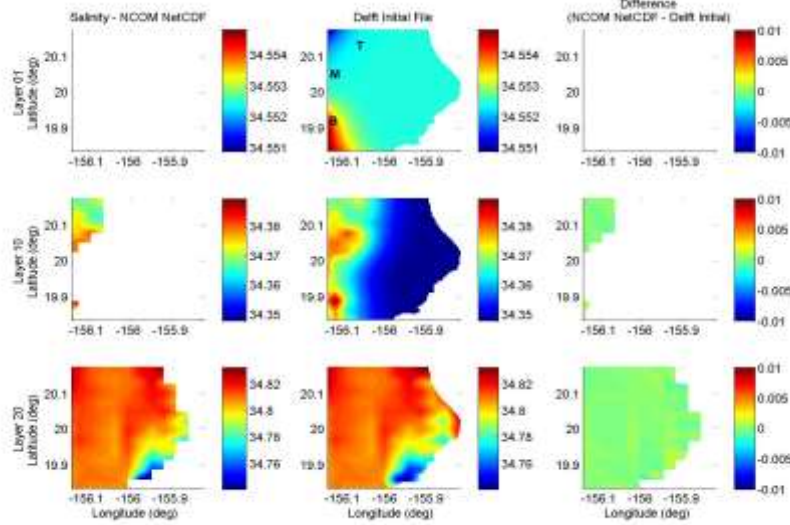


Figure 6. Salinity comparisons between the available NCOM data (nc-files) and the Delft3D ini-file for the Hawaii case for three Delft3D z-layers, the top (layer 20), the middle (layer 10), and the bottom (layer 1).

expected no data at depth will be evident in the model-model comparisons presented in Section IV.C.

B. Boundary Condition File Generation

In addition to the initialization files, we need to examine the boundary condition files. For the Maui 3D and Hawaii cases, we will compare values for the Riemann boundary condition as well as temperature and salinity. These Delft3D boundary conditions are created at a specified temporal resolution given the NCOM data. In Figure 8, we see comparisons of the Riemann, temperature, and salinity boundary conditions for the Maui 3D case. The comparison is for a boundary segment at the middle of the eastern lateral boundary (Figure 7). End B is nearly the mid-point of the eastern lateral boundary. At End B of this boundary segment, the model depths are nearly identical. At End A, however, the model depths differ and the results of internal diffusion are evident in the Delft3D boundary condition generation. Again, we note that the portion of the boundary condition profile where NCOM data is available is unchanged by the internal diffusion. The profiles in Figure 8 show that there is no difference in the NCOM data and the Delft3D boundary condition file. Time series comparisons of the three boundary condition parameters for the same boundary segment confirm this observation. The time series comparisons for the surface layer (Figure 8) show that the data-boundary condition file agreement holds through time with only the slightest of deviation from each other. The deviations exist because the boundary condition is interpolated in time to provide information every hour; the NCOM results provide data every 3 hours. Although not shown, the comparisons for the Hawaii domain are similar in quality to the Maui 3D NCOM-Delft3D boundary condition comparisons.

C. Model-Model Comparisons

1) Maui 3D Case

Salinity profiles at the three Points labeled A, B, and C in Figure 3, show comparisons between Delft3D and NCOM results (Figure 9). As seen in the comparison of the initialization file, the two models are in agreement at the beginning of the run. Comparisons at Points A and B show only slight disagreement in the profiles as the model progresses. Point C, however, shows

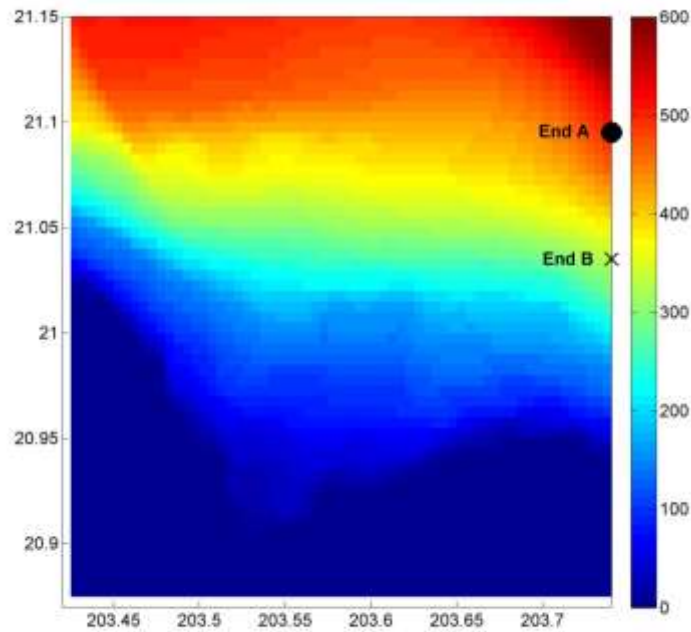


Figure 7. Delft3D bathymetry for the Maui case and boundary segment end points A and B for the second segment on the Eastern lateral boundary.

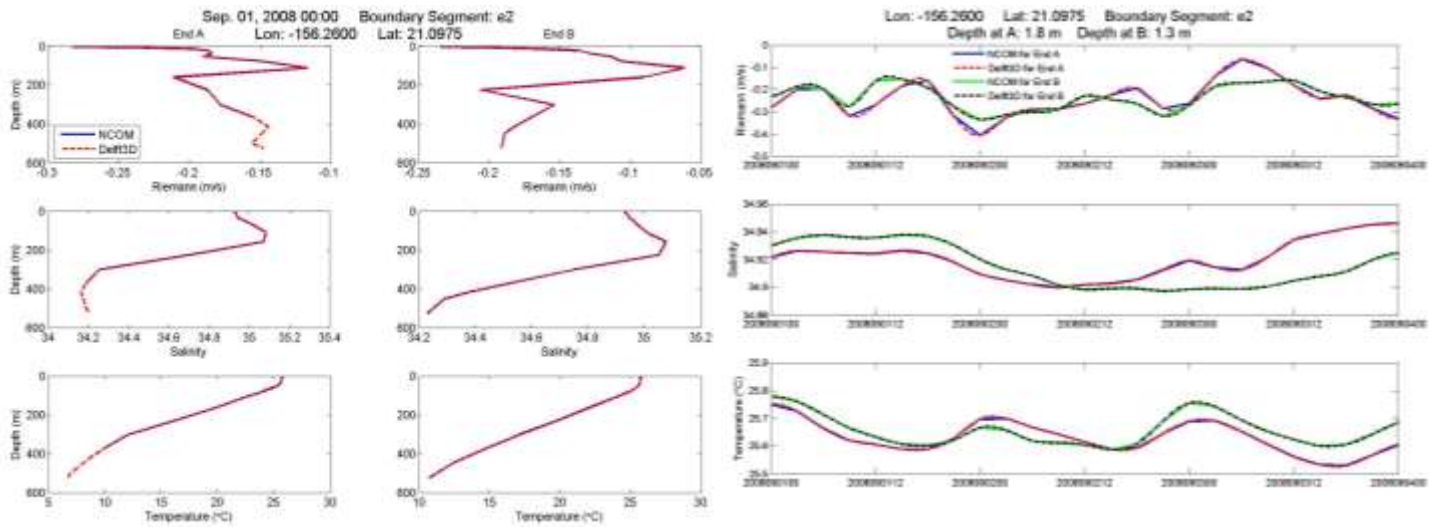


Figure 8. **Left:** Profile comparisons of the Riemann, temperature, and salinity boundary conditions for Maui 3D's e2 boundary segment. Comparisons between the NCOM data (blue line) and Delft3D boundary condition files (red dashed line) are shown for each end of the boundary segment. **Right:** Time series comparison of NCOM data (solid lines) and Delft3D boundary condition file (dashed lines) for the Maui 3D domain. This comparison is for the e2 boundary segment; ends A (red/blue) and B (green/black) are shown.

significant model disagreement as the model time increases. Furthermore, the disagreement increases with increased depth. These results are reiterated in a time series comparison of salinity predicted by the two models. Figure 9 shows time series comparisons of salinity near the surface (top), mid-depth (middle), and near the bottom (bottom) for Point C in the domain. The difference in model results are smallest near the surface and increase with depth. The quality of the comparison is relatively constant through time. These results hold true for Points A and B. It is the comparison at the bottom that is most interesting. The models begin with the same salinity at this depth, but as time increases, the model results diverge. There is no near-bottom comparison of salinity for Points A and B because there are no available NCOM results near the bottom of the Delft3D results. This results from the nc-file generation.

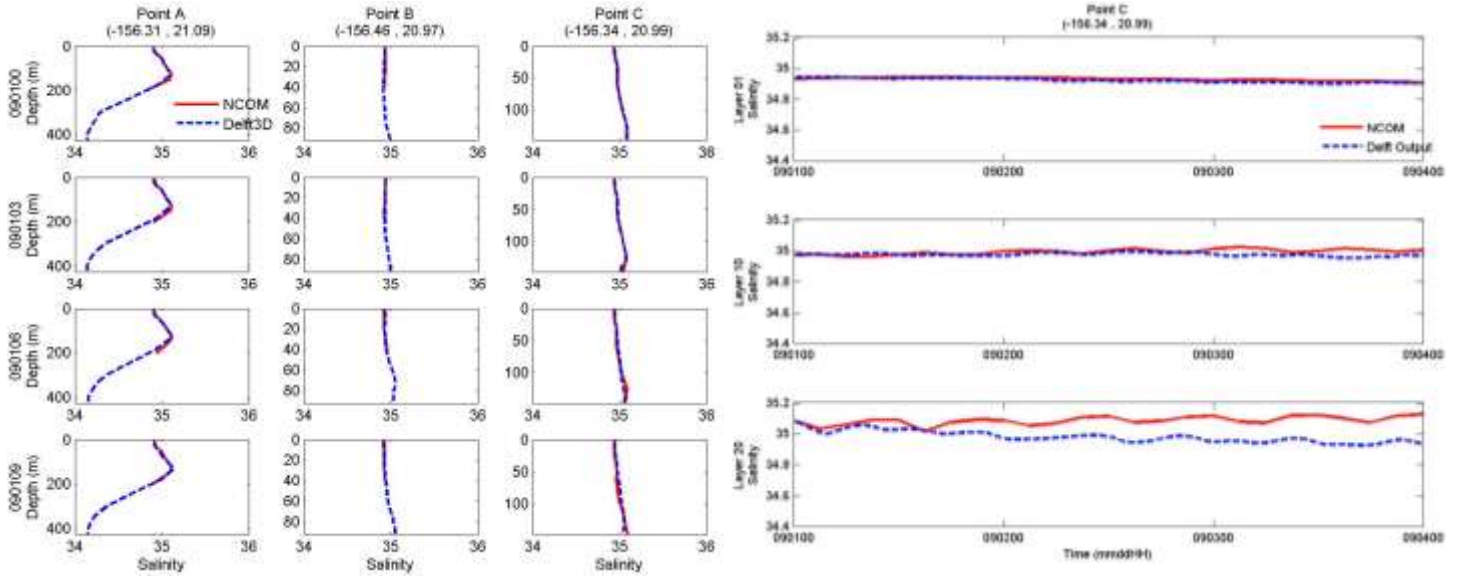


Figure 9. **Left:** Vertical profiles of salinity at three Points, A (left column), B (middle column), and C (right column), from the Maui 3D test case. Time increases by one hour from top row to bottom row. Delft3D (blue dash) and NCOM (red line) are compared. **Right:** Time series comparisons of salinity at Point C from the Maui 3D test case. The top shows a near surface comparison; the middle shows a mid-depth comparison, and the bottom shows a near bottom comparison. Delft3D (red dash) and NCOM (blue line) results are shown.

We examine similar plots for modeled temperature. Figure 10 shows modeled temperature profiles. Like with salinity, the observation point in deepest water, Point A, varies most with depth. At shallower depths, the water is more mixed and parameters vary less. At Points A and C, the difference in model results increases as the models progress in time. Increased differences are observed as depth increases. In the upper 50 meters depth, the models agree best. As the temperature begins decreasing with depth, discrepancies increase with Points A and C having similar discrepancies in temperature. Similarly to the comparisons of salinity, Figure 10 confirms what was observed in the profile plots. There is not much change in temperature over time and model agreement degrades with depth. Different from the comparisons of salinity is the fact that near the bottom, the model results do not diverge with time.

Finally, in Figure 11, we consider model-model comparisons of velocity. Rather than show differences in magnitude and direction separately, we show the velocity vector error with respect to the two models. For error to be low, the models must agree in both magnitude and direction. These comparisons do not provide information on what causes the error. In Figure 11, we see a

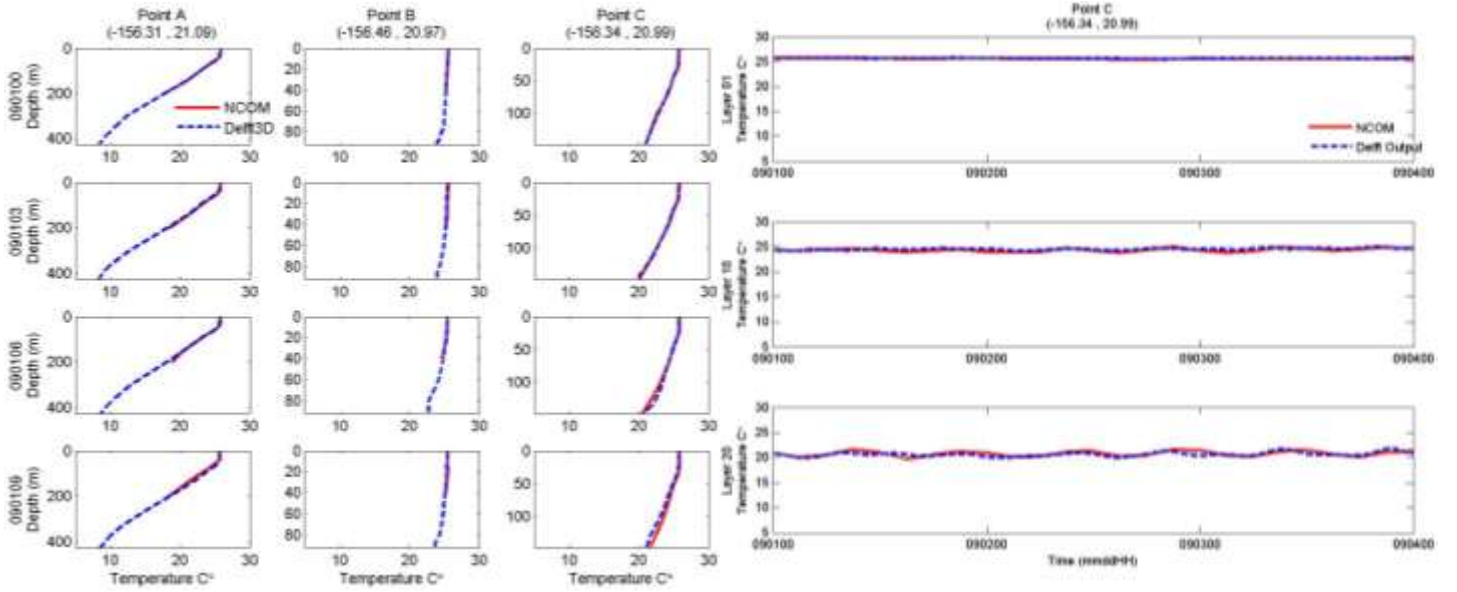


Figure 10. **Left:** Profile comparisons of temperature at Points A (left), B (middle), and C (right) in the Maui domain. The top row shows results from the beginning of the model runs. Model time increase as you move down the rows. Delft3D (blue dash) and NCOM (red line) results are shown. **Right:** Time series comparisons of temperature at Point C in the Maui domain. The top shows a near surface comparison; the middle shows a mid-depth comparison, and the bottom shows a near bottom comparison. Delft3D (red dash) and NCOM (blue line) results are shown.

similar story to what was observed in the comparisons of temperature and salinity. At all three locations in the domain, the error is near zero at the beginning of the model runs; this is true through the water column. Note that at Point A, we have an error for only the depths where results from both models exist. The comparisons at Points A and B show that the error is near or less than 0.2 m/s. While we can't say the error increases with depth, we can say that it seems to be more variable with depth. As with salinity, the largest errors occur at Point C. In this case, the large errors in excess of 0.2 m/s at Point C are caused by a jet-like feature that forms in the Delft3D results. This feature is most dominant and concentrated near the coast in the surface layer; it disperses and diminishes with depth (Figure 11). Therefore, near the surface, Point C comparisons are similar to Point A and Point B comparisons, but as depth increases and the jet-like feature affects the Delft3D model results at Point C, the errors increase. Near the bottom, the jet-like feature no longer affects the Delft3D results at Point C, and the errors decrease to values similar to the errors at Points A and B.

2) *Hawaii Case*

The NCOM-Delft3D comparisons of water level show good agreement. Near the beginning of the simulation, the difference is nearly zero (Figure 12). Although the difference increases with forecast time, it does not exceed 0.1 meter for this simulation.

Furthermore, salinity comparisons show good agreement between the two models. Figure 13 shows very little difference between the results—less than 0.05. The largest difference is at the surface (layer 20 because the vertical layers are z-levels).

The comparisons of temperature, however, show much greater variation in the model results. Again, the largest differences are seen in the surface layer (Figure 13), and they increase with

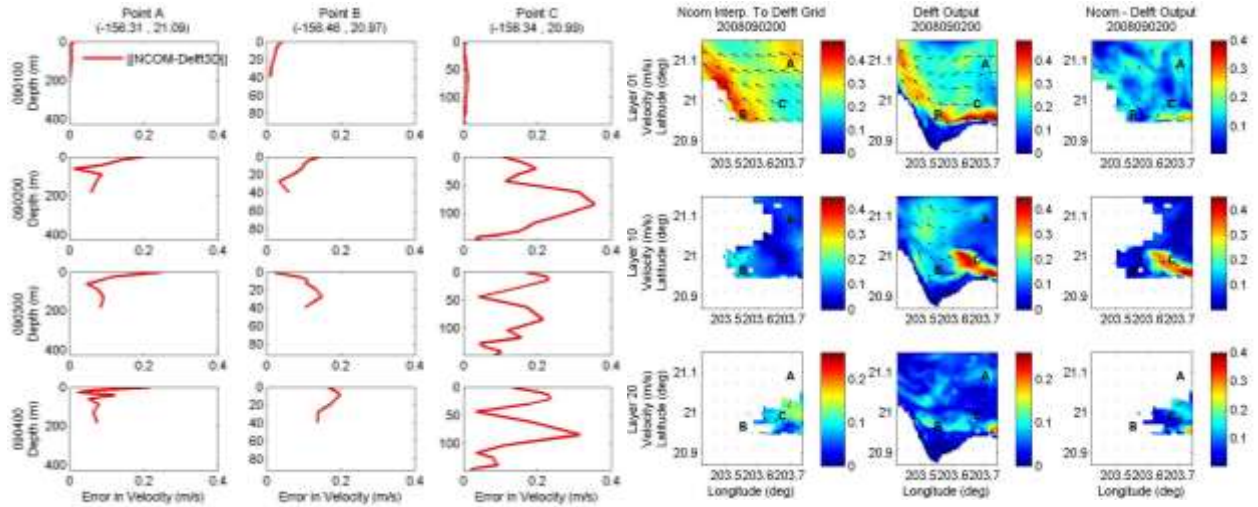


Figure 11. **Left:** Profile comparisons of velocity error at Points A (left), B (middle), and C (right) in the Maui domain. Model time increase as you move down the rows. **Right:** Velocity comparisons between the NCOM and Delft3D results for the Maui case near the surface (top row), mid-depth (middle row), and near bottom (bottom row).

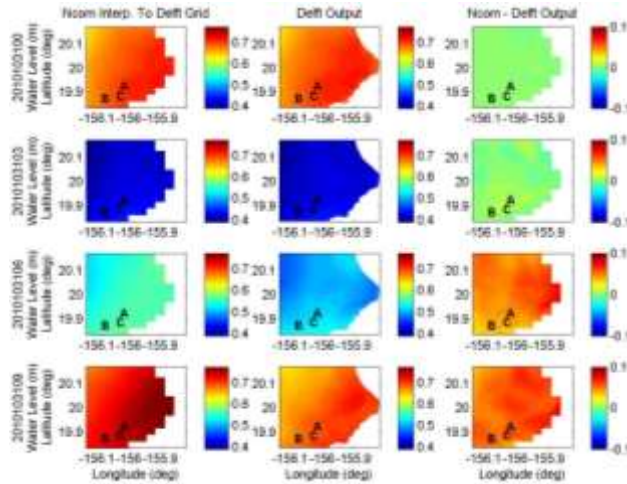


Figure 12. Comparison of NCOM (left) and Delft3D (middle) water levels. Model time increases with each row.

forecast time. These differences are near 0.5 degrees for much of the domain. In one area closer to shore, the difference tops 1.0 degree. We note, that the temperature range for the domain varies more than the salinity; therefore, larger differences in temperature are expected and more tolerable.

Comparisons of velocity show that, unlike the temperature and salinity comparisons, modeled velocities compare best at the surface. For the vast majority of the domain, surface velocity magnitudes differ by less than 0.15 m/s. As depth increases, differences in velocity magnitude increase and top 0.3 m/s. Visually, the velocity directions agree well.

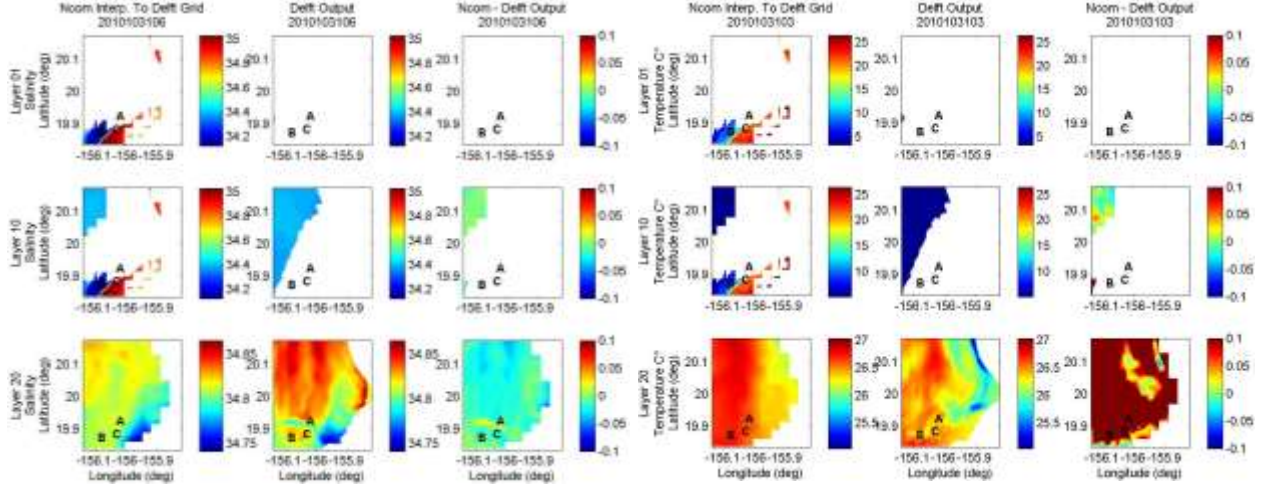


Figure 13. **Left:** Salinity comparison for near surface (top), mid-depth (middle), and near bottom (bottom) layers of the Hawaii domain. NCOM (left) and Delft3D (middle) results and a difference (right) are shown. **Right:** Temperature comparison for near surface (top), mid-depth (middle), and near bottom (bottom) layers of the Hawaii domain. NCOM (left) and Delft3D (middle) results and a difference (right) are shown.

3) *Maui 2D*

Because 2D Delft3D simulations compute depth averaged velocities and NCOM is a 3D model, for the Maui 2D case, we consider model-model comparisons for only water levels. Like water level predictions for the other model test cases, NCOM and Delft3D compare well. This is shown in Figure 14. The only notable differences in water level between the two models result from model output temporal resolution. Where NCOM output is provided every 3 hours, Delft3D output is provided every hour.

IV. CONCLUSIONS

We have constructed Delft3D initialization and boundary condition files for two Delft3D domains—one on the Maui coast and one on the Hawaii coast—given regional NCOM model output. The Maui test case exists as 2D and 3D Delft3D applications and the Hawaii test case uses z-levels for the third dimension. Together these Delft3D applications provide a variety of Delft3D setup options.

We investigated the Delft3D initialization and boundary condition files generated given the NCOM model results and compared the data written to the Delft3D files to the NCOM data. The comparisons prove that the routines used to generate the Delft3D files perform as expected and create Delft3D files that accurately portray environmental conditions predicted by NCOM. It was determined that the routines work for all of the vertical coordinate systems and boundary condition types encountered in the model test cases. These include sigma and z-level vertical coordinates, water level and Riemann boundary conditions, and temperature and salinity boundary conditions.

Because the Delft3D model test cases have horizontal resolutions more on the scale of a regional or coastal model rather than the scale of a nearshore model, the Delft3D results were compared to the NCOM results. As expected, the two models compared reasonably with differences likely caused by differences in resolution, bathymetry, and model physics rather than the initial and boundary condition specification.

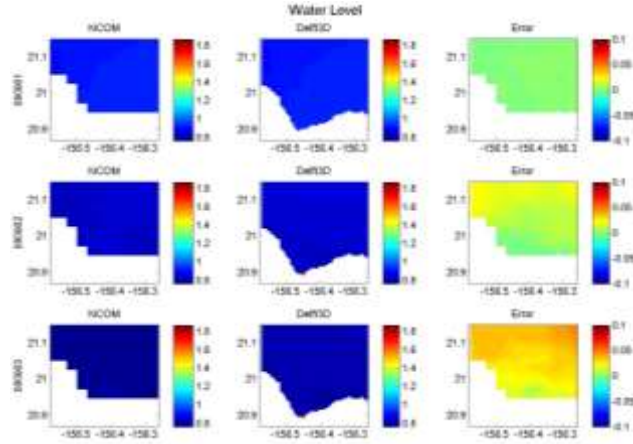


Figure 14. Water level comparisons for the 2 dimensional Maui test case. NCOM (left) and Delft3D (middle) results and a difference between the two (right) are shown for several model output times. Time increases with each row.

Overall, the routines developed to generate Delft3D boundary conditions from NCOM model results perform well and provide a useful alternative to tidal databases for operational forecasting with Delft3D.

ACKNOWLEDGMENT

This work was funded by SPAWAR under the Nearshore Wave and Surf Prediction project. A very special thanks to Maarten van Ormondt of Deltares in Delft, Netherlands for his work and contributions in developing the initial and boundary condition generation routines, to Jeikook Choi of the Naval Oceanographic Office and Jayaram Veeramony of NRL for providing the Delft3D test cases.

REFERENCES

- [1] Hsu, Y.L., J.D. Dykes and R.A. Allard and D. W. Wang, 2007: Validation test report for Delft3D, NRL memorandum report, NRL/MR/7320-08-9079, 42pp.
- [2] G. S. Stelling, "A non-hydrostatic flow model in cartesian coordinates: technical note," Z0901-10, WL | Delft Hydraulics, The Netherlands, January 1996.
- [3] G. R. Lesser, J. A. Roelvink, J. A. T. M van Kester, and G. S. Stelling, "Development and validation of a three-dimensional morphological model," Coastal Engineering, vol. 51, pp. 883-915, 2004.
- [4] Ris, R.C., L.H. Holthuijsen, and N. Booij, "A third-generation wave model for coastal regions 2. Verification," Journal of Geophysical Research, 104(C4), pp. 7667-7681, 1999.
- [5] Barron, C.N., A.B. Kara, P.J. Martin, R.C. Rhodes, and L.F. Smedstad, (2006). Formulation, implementation and examination of vertical coordinate choices in the Global Navy Coastal Ocean Model (NCOM). Ocean Modelling, 11: 347-375.